UNITED STATES DEPARTMENT OF COMMERCE
MAURICE H. STANS, Secretary
NATIONAL BUREAU OF STANDARDS / LEWIS M. BRANSCOMB, Director
Special Publication 304A. Issued 1968
Revised 1970

Brief History and Use of

THE ENGLISH AND METRIC SYSTEMS OF MEASUREMENT

with a

CHART OF THE MODERNIZED METRIC SYSTEM

"Weights and measures may be ranked among the necessaries of life to every individual of human society. They enter into the economical arrangements and daily concerns of every family. They are necessary to every occupation of human industry; to the distribution and security of every species of property; to every transaction of trade and commerce; to the labors of the husbandman; to the ingenuity of the artificer; to the studies of the philosopher; to the researches of the antiquarian, to the navigation of the mariner, and the marches of the soldier; to all the exchanges of peace, and all the operations of war."

—JOHN QUINCY ADAMS

When the American Colonies separated from the mother country to assume among the nations of the earth a separate and individual station, they retained, among other things, the weights and measures that had been used when they were colonies, namely, the weights and measures of England. It is probable that these were at that time the best standardized and widely used weights and measures in the world.

England, a highly coherent nation, separated by sea from many of the turmoils of the European continent, had long before established standards for weights and measures that have remained essentially unchanged up to the present time. The yard, standardized by Henry II, differs only by about 1 part in a thousand from the yard of today. The pound of Queen Elizabeth I shows similar agreement with the present avoirdupois pound.

No such uniformity of weights and measures existed on the European continent. Weights and measures differed not only from country to country, but even from town to town and from one trade to another. This lack of uniformity led the National Assembly of France on May 8, 1790, to enact a decree, sanctioned by Louis XVI, which called upon the French Academy of Sciences in concert with the Royal Society of London to "deduce an invariable standard for all of the measures and all weights." However, the English did not participate in the French undertaking, so the French proceeded with their endeavor alone. The result is what is known as the metric system.

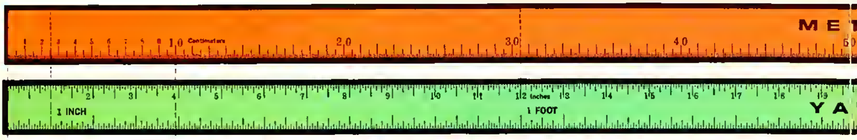
The metric system was conceived as a measurement system to the base ten; that is, the units of the system, their multiples, and submultiples should be related to each other by simple factors of ten. This is a great convenience because it conforms to our common system for numerical notation, which is also a base ten system. Thus to convert between units, their multiples, and submultiples, it is not necessary to perform a difficult multiplication or division process, but simply to shift the decimal point. The system seems to have been first proposed by Gabriel Mouton, a vicar of Lyons, France, in the late 17th century. He proposed to define the unit of length for the system as a fraction of the length of a great circle of the earth. This idea found favor with the French philosophers at the time of the French Revolution, men who were generally opposed to any vestige of monarchical authority and preferred a standard based on a constant of nature.

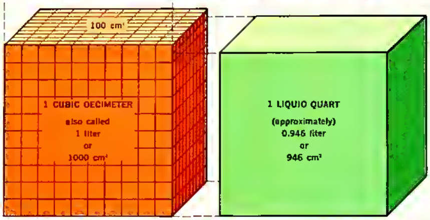
The French Academy assigned the name mètre (meter), from the Greek *metron*, a measure, to the unit of length which was supposed to be one ten millionth of the distance from the north pole to the equator, along the meridian running near Dunkirk, Paris, and Barcelona. An attempt was made to measure this meridian from northern France to southern France, from which the true distance from the pole to the equator could be calculated. The best techniques then available were used. Although the operations were carried out during a politically disturbed time, the results were in error only by about 2000 meters, a remarkable achievement in those days.

Meanwhile the National Assembly preempted the geodetic survey, upon which the meter was to be based, and established a provisional meter bar. The unit of mass called the gram was decided on as the mass of one cubic centimeter of water at its temperature of maximum density. Since this was too small a quantity to be measured

For sale by the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402—Price 20 cents

The Modernized Metric Sys



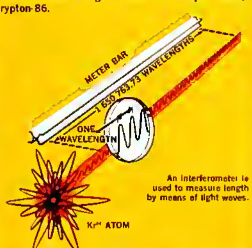


THE International System of Units—a
viated SI—is a modernized version
system. It was established by inter
ment to provide a logical and interconnect
for all measurements in science, industry, a
SI is built upon a foundation of base units
nitions, which appear on this chart. All oth

The Six Base Units of Measurem

Length METER–m

The meter is defined as 1 650 763.73 wavelengths in vacuum of the orange-red line of the spectrum of krypton-86.



An interferometer is used to measure length by means of light waves.

The SI unit of area is the square meter (m^2). Land is often measured by the hectare (10 000 square meters, or approximately 2.5 acres).

The SI unit of volume is the cubic meter (m^3). Fluid volume is often measured by the liter (0.001 cubic meter).

National Bureau of Standards Special Publication 304 A

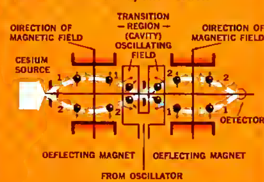
For sale by the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402 · Price 20 cents

References:

NBS Spec. Publ. 330, International System of Units (in press)
NBS Misc. Publ. 247, Weights and Measures Standards of the United States, A Brief History, 40 cents
NBS Misc. Publ. 286, Units of Weight and Measure, Definitions and Tables of Equivalents, $2.25

Time SECOND–s

The second is defined as the duration of 9 192 631 770 cycles of the radiation associated with a specified transition of the cesium atom. It is realized by tuning an oscillator to the resonance frequency of the cesium atoms as they pass through a system of magnets and a resonant cavity into a detector.



A schematic of an atomic beam spectrometer. The trajectories are drawn for those atoms whose magnetic moments are "flipped" in the transition region.

The number of periods or cycles per second is called frequency. The SI unit for frequency is the hertz (Hz). One hertz equals one cycle per second.

Standard frequencies and correct time are broadcast from NBS stations WWV, WWVB, WWVH, and WWVL, and stations of the U.S. Navy.

Many shortwave receivers pick up WWV on frequencies of 2.5, 5, 10, 15, 20, and 25 megahertz. The standard radio broadcast band extends from 535 to 1605 kilohertz.

Dividing distance by time gives speed. The SI unit for speed is the meter per second (m/s).

Rate of change in speed is called acceleration. The SI unit for acceleration is the meter per second per second (m/s^2).

Mass KILOGRAM–kg

The standard for the unit of mass, the kilogram, is a cylinder of platinum-iridium alloy kept by the International Bureau of Weights and Measures at Paris. A duplicate in the custody of the National Bureau of Standards serves as the mass standard for the United States. This is the only base unit still defined by an artifact.

U.S. PROTOTYPE KILOGRAM NO. 20

Closely allied to the concept of mass is that of force. The SI unit of force is the newton (N). A force of 1 newton, when applied for 1 second, will give to a 1 kilogram mass a speed of 1 meter per second (an acceleration of 1 meter per second per second).

$$1N = \frac{1kg \cdot 1m}{1s^2}$$

One newton equals approximately two tenths of a pound of force.

The weight of an object is the force exerted on it by gravity. Gravity gives a mass a downward acceleration of about 9.8 m/s^2.

The SI unit for work and energy of any kind is the joule (J).

$$1J = 1N \cdot 1m$$

The SI unit for power of any kind is the watt (W).

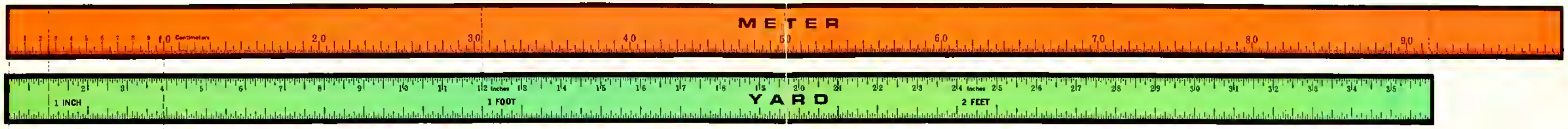
$$1W = \frac{1J}{1s}$$

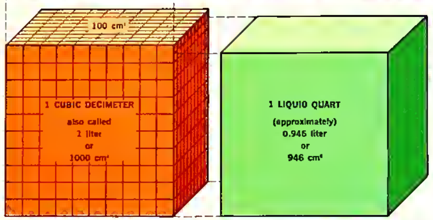
A full-scale wall chart, NBS Special Publication 304, is available from the Superintendent

The Modernized Metric System

The International System of Units (SI) and its relationship to U.S. customary units

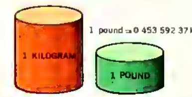
U.S. DEPARTMENT OF COMMERCE
National Bureau of Standards





THE International System of Units—officially abbreviated SI—is a modernized version of the metric system. It was established by international agreement to provide a logical and interconnected framework for all measurements in science, industry, and commerce. SI is built upon a foundation of base units and their definitions, which appear on this chart. All other SI units are derived from these base units. Multiples and submultiples are expressed in a decimal system. Use of metric weights and measures was legalized in the United States in 1866, and our customary units of weights and measures are defined in terms of the meter and the kilogram. The legal units for electricity and illumination in the United States are SI units.

The comparative dimensions of the meter and the yard, the liter and the quart, and the kilogram and the pound are shown.

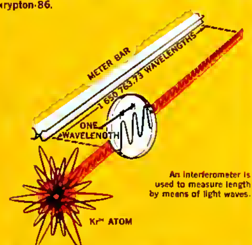


The Six Base Units of Measurement

definitions, symbols, and some SI units derived from them

Length METER—m

The meter is defined as 1 650 763.73 wavelengths in vacuum of the orange-red line of the spectrum of krypton-86.



An interferometer is used to measure length by means of light waves.

The SI unit of area is the square meter (m^2). Land is often measured by the hectare (10 000 square meters, or approximately 2.5 acres).

The SI unit of volume is the cubic meter (m^3). Fluid volume is often measured by the liter (0.001 cubic meter).

National Bureau of Standards Special Publication 304 A

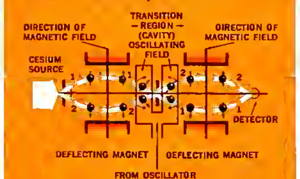
For sale by the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402 · Price 20 cents

References:

NBS Spec. Publ. 330, International System of Units (in press)
NBS Misc. Publ. 247, Weights and Measures Standards of the United States, A Brief History, 40 cents
NBS Misc. Publ. 286, Units of Weight and Measure, Definitions and Tables of Equivalents, $2.25

Time SECOND—s

The second is defined as the duration of 9 192 631 770 cycles of the radiation associated with a specified transition of the cesium atom. It is realized by tuning an oscillator to the resonance frequency of the cesium atoms as they pass through a system of magnets and a resonant cavity into a detector.



A schematic of an atomic beam spectrometer. The trajectories are drawn for those atoms whose magnetic moments are "flipped" in the transition region.

The number of periods or cycles per second is called frequency. The SI unit for frequency is the hertz (Hz). One hertz equals one cycle per second.

Standard frequencies and correct time are broadcast from NBS stations WWV, WWVB, WWVH, and WWVL, and stations of the U.S. Navy.

Many shortwave receivers pick up WWV on frequencies of 2.5, 5, 10, 15, 20, and 25 megahertz. The standard radio broadcast band extends from 535 to 1605 kilohertz.

Dividing distance by time gives speed. The SI unit for speed is the meter per second (m/s).

Rate of change in speed is called acceleration. The SI unit for acceleration is the meter per second per second (m/s^2).

Mass KILOGRAM—kg

The standard for the unit of mass, the kilogram, is a cylinder of platinum-iridium alloy kept by the International Bureau of Weights and Measures at Paris. A duplicate in the custody of the National Bureau of Standards serves as the mass standard for the United States. This is the only base unit still defined by an artifact.

U.S. PROTOTYPE KILOGRAM NO. 20

Closely allied to the concept of mass is that of force. The SI unit of force is the newton (N). A force of 1 newton, when applied for 1 second, will give to a 1 kilogram mass a speed of 1 meter per second (an acceleration of 1 meter per second per second).

$$1N = \frac{1kg \cdot 1m}{1s^2}$$

One newton equals approximately two tenths of a pound of force.

The weight of an object is the force exerted on it by gravity. Gravity gives a mass a downward acceleration of about 9.8 m/s^2.

The SI unit for work and energy of any kind is the joule (J).

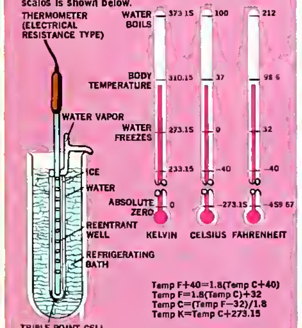
$$1J = 1N \cdot 1m$$

The SI unit for power of any kind is the watt (W).

$$1W = \frac{1J}{1s}$$

Temperature KELVIN—K

The thermodynamic or Kelvin scale of temperature used in SI has its origin or zero point at absolute zero and has a fixed point at the triple point of water defined as 273.16 kelvins. The Celsius scale is derived from the Kelvin scale. The triple point is defined as 0.01 °C on the Celsius scale, which is approximately 32.02 °F on the Fahrenheit scale. The relationship of the Kelvin, Celsius, and Fahrenheit temperature scales is shown below.

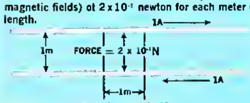


Temp F+40=1.8(Temp C+40)
Temp F=1.8(Temp C)+32
Temp C=(Temp F−32)/1.8
Temp K=Temp C+273.15

The triple point cell, an evacuated glass cylinder filled with pure water, is used to define a known fixed temperature. When the cell is cooled until a mantle of ice forms around the reentrant well, the temperature at the interface of solid, liquid, and vapor is 0.01 °C. Thermometers to be calibrated are placed in the reentrant well.

Electric Current AMPERE—A

The ampere is defined as the magnitude of the current that, when flowing through each of two long parallel wires separated by one meter in free space, results in a force between the two wires (due to their magnetic fields) of 2×10^{-7} newton for each meter of length.



The SI unit of voltage is the volt (V).

$$1V = \frac{1W}{1A}$$

The SI unit of electrical resistance is the ohm (Ω).

$$1\Omega = \frac{1V}{1A}$$

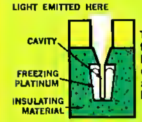
COMMON EQUIVALENTS AND CONVERSIONS

Approximate Common Equivalents		Conversions Accurate to Parts Per Million	
1 inch	= 25 millimeters	inches x 25.4*	= millimeters
1 foot	= 0.3 meter	feet x 0.3048*	= meters
1 yard	= 0.9 meter	yards x 0.9144*	= meters
1 mile	= 1.6 kilometers	miles x 1.609 34	= kilometers
1 square inch	= 6.5 sq centimeters	square inches x 6.4516*	= sq centimeters
1 square foot	= 0.09 square meter	square feet x 0.092 903 0	= square meters
1 square yard	= 0.8 square meter	square yards x 0.836 127	= square meters
1 acre	= 0.4 hectare †	acres x 0.404 686	= hectares
1 cubic inch	= 16 cu centimeters	cubic inches x 16.3871	= cu centimeters
1 cubic foot	= 0.03 cubic meter	cubic feet x 0.028 316 8	= cubic meters
1 cubic yard	= 0.8 cubic meter	cubic yards x 0.764 555	= cubic meters
1 quart (lq)	= 1 liter †	quarts (lq) x 0.946 353	= liters
1 gallon	= 0.004 cubic meter	gallons x 0.003 785 41	= cubic meters
1 ounce (avdp)	= 28 grams	ounces (avdp) x 28.3495	= grams
1 pound (avdp)	= 0.45 kilogram	pounds (avdp) x 0.453 592	= kilograms
1 horsepower	= 0.75 kilowatt	horsepower x 0.745 700	= kilowatts
1 millimeter	= 0.04 inch	millimeters x 0.039 370 1	= inches
1 meter	= 3.3 feet	meters x 3.280 84	= feet
1 meter	= 1.1 yards	meters x 1.093 61	= yards
1 kilometer	= 0.6 mile	kilometers x 0.621 371	= miles
1 sq centimeter	= 0.16 square inch	sq centimeters x 0.155 000	= square inches
1 square meter	= 11 square feet	square meters x 10.7639	= square feet
1 square meter	= 1.2 square yards	square meters x 1.195 99	= square yards
1 hectare †	= 2.5 acres	hectares x 2.471 05	= acres
1 cu centimeter	= 0.06 cubic inch	cu centimeters x 0.061 023 7	= cubic inches
1 cubic meter	= 35 cubic feet	cubic meters x 35.3147	= cubic feet
1 cubic meter	= 1.3 cubic yards	cubic meters x 1.307 95	= cubic yards
1 liter †	= 1 quart (lq)	liters x 1.056 69	= quarts (lq)
1 cubic meter	= 250 gallons	cubic meters x 264.172	= gallons
1 gram	= 0.035 ounce (avdp)	grams x 0.035 274 0	= ounces (avdp)
1 kilogram	= 2.2 pounds (avdp)	kilograms x 2.204 62	= pounds (avdp)
1 kilowatt	= 1.3 horsepower	kilowatts x 1.341 02	= horsepower

† common term not used in SI
* exact

Luminous Intensity CANDELA—cd

The candela is defined as the luminous intensity of 1/600 000 of a square meter of a radiating cavity at the temperature of freezing platinum (2042 K).



The SI unit of light flux is the lumen (lm). A source having an intensity of 1 candela in all directions radiates a light flux of 4π lumens.

A 100-watt light bulb emits about 1700 lumens

THESE PREFIXES MAY BE APPLIED TO ALL SI UNITS

Multiples and Submultiples	Prefixes	Symbols
1 000 000 000 000 = 10^{12}	tera (ter'a)	T
1 000 000 000 = 10^{9}	giga (ji'ga)	G
1 000 000 = 10^{6}	mega (meg'a)	M *
1000 = 10^{3}	kilo (kil'ō)	k *
100 = 10^{2}	hecto (hek'tō)	h
10 = 10	deka (dek'a)	da
0.1 = 10^{-1}	deci (des'i)	d
0.01 = 10^{-2}	centi (sen'ti)	c *
0.001 = 10^{-3}	milli (mil'i)	m *
0.000 001 = 10^{-6}	micro (mī'krō)	μ *
0.000 000 001 = 10^{-9}	nano (nan'ō)	n
0.000 000 000 001 = 10^{-12}	pico (pē'kō)	p
0.000 000 000 000 001 = 10^{-15}	femto (fem'tō)	f
0.000 000 000 000 000 001 = 10^{-18}	atto (at'tō)	a

*Most commonly used

A full-scale wall chart, NBS Special Publication 304, is available from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402, for 50 cents.

with the desired precision the determination was made on one cubic decimeter of water, and metal weights of equivalent mass were constructed for standards. But although the determination was subsequently found to be in error by about 28 parts in a million, the metal weights were still retained as standards.

Thus, the meter bar that was established as the foundation of the system did not approximate the intended definition on which it was based with the desired accuracy. Also the unit of mass differed from the intended definition even as given in terms of the erroneously established meter. So the new system was actually based on two metallic standards not differing greatly in nature from the yard of Henry II or the pound of Elizabeth I.

As a unit for fluid capacity, the founders selected the cubic decimeter and as a unit for land area they selected the are, equal to a square ten meters on the side. In this manner, while decimal relationships were preserved between the units of length, fluid capacity, and area, the relationships were not kept to the simplest possible form. Although there was some discussion at the time of decimalizing the calendar and the time of day, the system did not include any unit for time.

The British system of weights and measures, and the metric system as well, had been developed primarily for use in trade and commerce rather than for purposes of science and engineering.

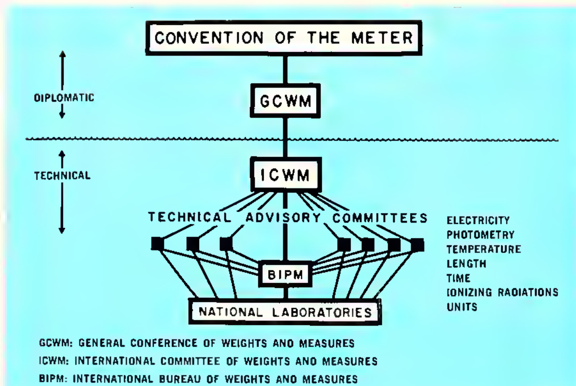
Because technological achievement depends to a considerable extent upon the ability to make physical measurements, the Americans and the British proceeded to adapt their system of measurements to the requirements of the new technology of the 19th century, despite the fact that the newly developed metric system seemed to have certain points of superiority. Both the United States and Great Britain soon had vast investments in a highly industrialized society based on their own system.

The new metric system found much favor with scientists of the 19th century, partly because it was intended to be an international system of measurement, partly because the units of measurement were theoretically supposed to be independently reproducible, and partly because of the simplicity of its decimal nature. These scientists proceeded to derive new units for the various physical quantities with which they had to deal, basing the new units on elementary laws of physics and relating them to the units of mass and length of the metric system. The system found increasing acceptance in various European countries which had been plagued by a plethora of unrelated units for different quantities.

Because of increasing technological development there was a need for international standardization and improvements in the accuracy of standards for units of length and mass. This led to an international meeting in France in 1872, attended by 26 countries including the United States. The meeting resulted in an international treaty, the Metric Convention, which was signed by 17 countries, including the United States in 1875. This treaty set up well defined metric standards for length and mass, and established the International Bureau of Weights and Measures. Also established was the General Conference of Weights and Measures, which would meet every six years to consider any needed improvements in the standards and to serve as the authority governing the International Bureau. An International Committee of Weights and Measures was also set up to implement the recommendations of the General Conference and to direct the activities of the International Bureau; this Committee meets every two years.

Since its inception nearly 175 years ago, the number of countries using the metric system has been growing rapidly. The original metric system of course had imperfections; and it has since undergone many revisions, the more recent ones being accomplished through the General Conference of Weights and Measures. An extensive revision and simplification in 1960 by the then 40 members of the General Conference resulted in a modernized metric system—the International System of Units—which is described in detail in the accompanying chart.

NOTE: For further information see the references listed on the chart.



INTERNATIONAL COORDINATION OF MEASUREMENT STANDARDS

☆ U. S. GOVERNMENT PRINTING OFFICE : 1970 O - 402-569